PREDICTION OF AIR QUALITY OVER TOKYO METROPOLITAN AREA BY USING THE JCAP II AIR QUALITY SIMULATION SYSTEM

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1. INTRODUCTION

Air quality in Japan is getting improved, but some observational stations cannot meet the Japanese national air quality standard for some pollutants such as NO_2 and PM. Additional strategies may be necessary to improve air quality further. In order to consider new regulations on emission sources, it is desirable to evaluate future potential effectiveness of them by conducting air quality simulations. However, currently no official procedure and modeling system for the evaluation of new regulations are available in Japan. Japan Clean Air Program (JCAP) II developed the air quality simulation system to satisfy such kind of needs. In this paper, outlines and results of the prediction of effectiveness of the new regulation on vehicle emissions by using the JCAP II air quality simulation system are presented.

2. METHOD

The JCAP II air quality modeling system consists of the air quality model, the meteorological model and the emission inventory database. Details of each component and simulation cases conducted in this study are described in the following subsections.

2.1 Air Quality Model

CMAQ (Community Multi-scale Air Quality modeling system) (Byun and Ching, 1999) ver. 4.6 was used to simulate pollutant concentrations. Target domains in this study are shown in Fig. 1. Three nested domain, Asian, Japan G1 and Japan G2, were used. Asian domain covers eastern and southeastern Asian countries to take the transboundary transport of pollutants to Japan into account. Japan G1 domain covers the most part of Japan, and Japan G2 domain focuses on Kanto region including Tokyo metropolitan area where is facing the severest air pollution in Japan. Number of meshes is 114 x 114 x 24 in Asian domain, 68 x 64 x 27 in Japan G1 domain, and 40 x 44 x 33 in Japan G2 domain. Size of meshes is 64 x 64km in Asian domain, 16 x 16km in Japan G1 domain, and 4 x 4km in Japan G2 domain. The horizontal coordinate is based on the polar stereographic coordinate and the vertical coordinate is based on the sigma-z coordinate. Capabilities dealing with both coordinates in CMAQ were added by modifying source codes.

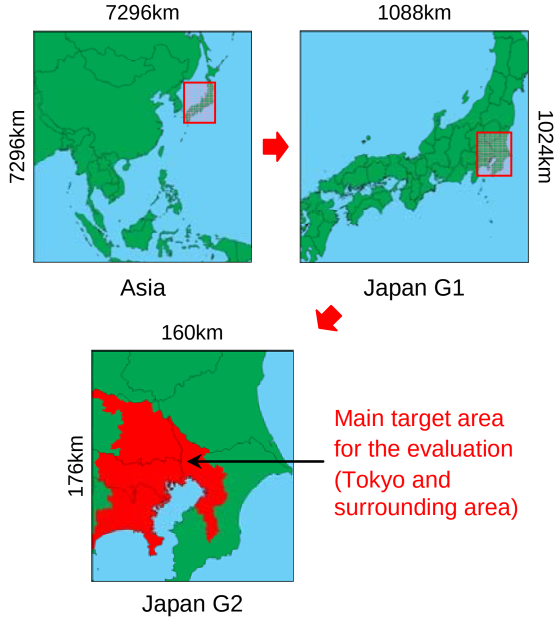

Fig. 1. Target domains of the simulation.

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2.2 Meteorological Model

RAMS (Regional Atmospheric Modeling System) (Pielke et al., 1992) ver. 4.4 was used to simulate meteorological field. Target domains are one-mesh larger than those of CMAQ shown in Fig. 1. ECWMF (European Centre for Medium-Range Weather Forecast) operational analysis data was utilized for the initial and boundary condition. MCIP developed by Sugata et al. (2001) was used to convert RAMS output to CMAQ meteorological input data.

2.3 Domestic Vehicle Emission data

We developed the JCAP II vehicle emission estimation model. Running emissions, cold-start emissions, evaporative emissions (running loss, hot soak loss, diurnal breathing loss), road dust and tire wear are estimated. This model follows methodologies similar to EMFAC and MOBILE. The estimation of running emissions is briefly described below as an example.

Running emissions are calculated by multiplying emission factors by traffic amounts. Basic emission factors have been prepared for each vehicle category and model year. They are corrected by considering influences of deterioration, speed, temperature and humidity on emissions. Traffic amounts were based on the census data developed by the government. They were allocated to each link on the digital road map, and were divided into meshes by GIS. In this study, resolution of meshes was about 10 x 10 km for whole Japan, and 1 x 1km within the Japan G2 domain including Tokyo metropolitan area.

Nowadays, vehicle exhaust emitted from new vehicles is getting cleaner, and high emissions from “high-emitters” (e.g. malfunctioned or tampered vehicles) have been concerned. In order to examine the status of high-emitters in the real world, the measurement at the roadside was conducted in which emissions from each vehicle were measured by Remote Sensing Devices (RSD). As an example, Fig. 2 shows average values and distributions of NO emissions measured by RSD. Vehicles with high emissions were found as the age is getting old. The ratio of high-emitters was derived by counting vehicles with emissions exceeding the threshold given for each pollutant. This ratio and the emission factors of high-emitters were used to estimate emissions from high-emitters.

Target years of estimating vehicle emissions were 1999 and 2015. For year 1999, data already available were utilized. For year 2015, emission factors and the distribution of model years were changed. Changes in other factors related to emissions (e.g. vehicle mileages traveled or new road constructions) were not considered.

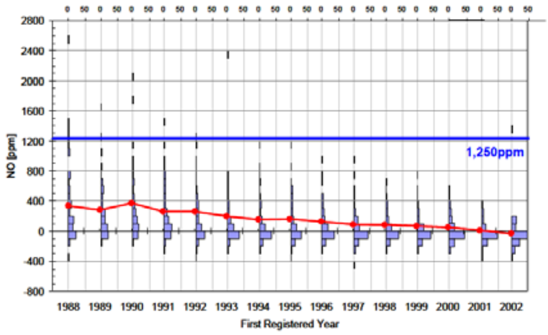

Fig. 2. Average values and distributions of NO emissions measured by RSD.

2.4 Other Emission Data

The emission inventory developed by Kannari et al. (2007) was used for Japanese domestic sources except for vehicles. Emissions from large stationary combustion sources, small combustion sources, ships, airplanes, machineries, stationary evaporative NMVOC sources, ammonia emission sources, incinerators, open burnings, and biogenic NMVOC are included in this inventory. Resolution of the data is 1km x 1km.

REAS (Regional Emission inventory in ASia, Ohara et al., 2007) ver. 1.1 was used for anthropogenic sources in Asian countries. GEIA emission data (Granier et al., 2005) was used for biogenic NMVOC and biomass burning in Asian countries.

Target year of all emission data except for domestic vehicles is 2000 and they were used in all of simulation cases in this study. Therefore, influences of future changes in emissions except for domestic vehicles and in the transboundary transport are not evaluated in this study.

2.5 Simulation Cases

Six simulation cases shown in Table 1 were conducted in this study. Case 1 is the case for reproducing the current status of air quality using vehicle emission data for year 1999. Estimated vehicle emission data for year 2015 was used in Case 2-4. Replacement with newer vehicles and regulations which have been already determined were considered in Case 2. A more stringent emission regulation was assumed in Case 3, and

NOx and PM emission factors of diesel vehicles in year 2008 and subsequent years were reduced by 50% and 25%, respectively. A regulation on high-emitters was assumed in Case 4, and the ratio of high-emitters was set to be zero. Vehicle emission data for year 1999 was used in Case 5 and 6, but the boundary concentration of the Japan G1 domain was changed to -50% and +50%, respectively, in order to examine influences of the transboundary transport.

Table 1. Simulation cases.

	Vehicle emission	Boundary conc.
Case 1	Year 1999	
Case 2	Year 2015	
Case 3	Year 2015 + New regulation from year 2008 [1]	
Case 4	Year 2015 + Excluding HE [2]	
Case 5	Year 1999	-50% in Japan G1
Case 6	Year 1999	+50% in Japan G1

1 : -50% and -25% of diesel NOx and PM EF from year 2008
2 : HE : High-emitters

The target period of the simulations is from Nov. 1^{st} to Dec. 10^{th}, 1999. Daily average concentrations on Dec. 10^{th} in the target area shown in Fig. 1 were mainly used for the evaluation in this study.

3. RESULTS

3.1 Estimated Emission

Estimated weekday vehicle NOx and SPM (equivalent to PM_7) emissions summed over the target area for Case 1-4 are shown in Fig. 3. In year 2015, vehicle NOx and SPM emissions were estimated to be reduced from year 1999 by 44% and 45%, respectively, only by the replacement with newer vehicles and current regulations. An additional regulation would reduce NOx emission further by 8%, but excluding high-emitters may be more effective than new regulations. Fraction of road dust and tire wear became larger in SPM emission, and influences of a new regulation on vehicle exhaust were negligible.

NOx and SPM emissions from all sources summed over the target area for Case 1-4 are shown in Fig. 4. 53% of NOx and 67% of SPM (40% from vehicle exhaust only) were estimated to be emitted from vehicles. Fraction of vehicles would be significantly reduced unless emissions from sources except for vehicles are reduced as well.

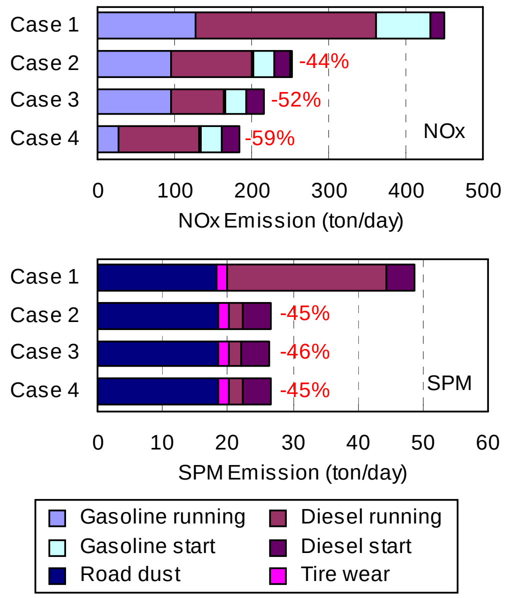

Fig. 3. Estimated weekday vehicle NOx and SPM emissions summed over the target area.

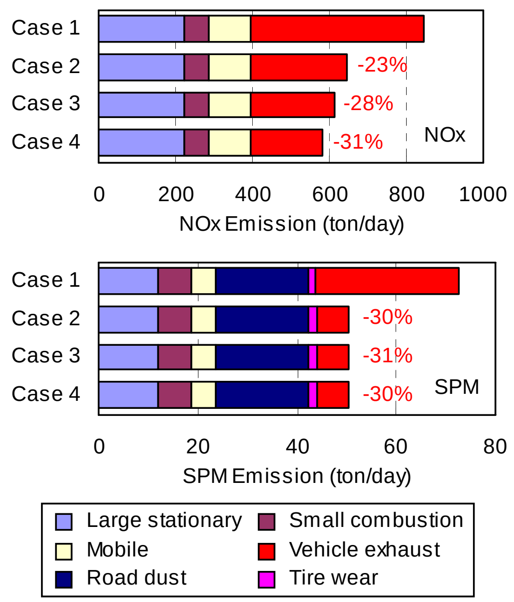

Fig. 4. Estimated NOx and SPM emissions from all sources summed over the target area.

3.2 Performance of the Air Quality Simulation

Time series of observed and simulated NO_2 and SPM concentrations in Case 1 at Kanda and Shirokane observational stations are shown in Fig. 5. Both stations are located in the center of Tokyo metropolitan area. Hourly variation of NO_2 was reproduced well but slightly underestimated especially in the evening of Dec. 10th, 1999. SPM was underestimated for most hours and peaks were not reproduced well.

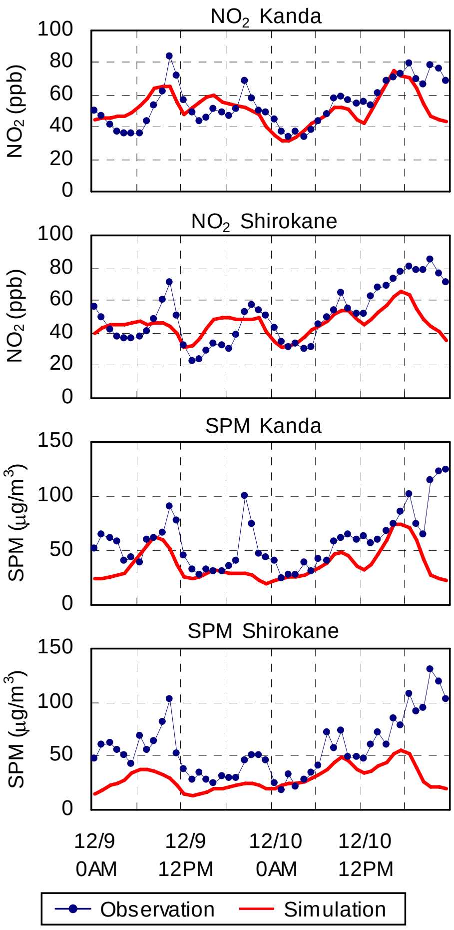

Fig. 5 Time series of observed and simulated NO_2 and SPM concentration.

Mean normalized bias (MNB) and mean normalized error (MNE) of daily NO_2 and SPM concentration on Dec. 10th, 1999 were calculated using observation data at about 200 stations located in the target area. Table 2 shows calculated MNB and MNE. MNB and MNE of NO_2 are reasonable, although the performance for SPM should be improved.

Table 2. MNB and MNE of daily NO_2 and SPM concentration on Dec. 10th, 1999 in the target area.

	MNB	MNE
NO_2	-17.9%	21.1%
SPM	-51.4%	53.3%

3.3 Predicted Pollutant Concentrations

Predicted daily NO_2 and SPM concentration on Dec. 10th, 1999 averaged over the target area in Case 1-4 are shown in Fig. 6. NO_2 and SPM concentrations were reduced in a similar way as NOx and SPM emissions. However, reduction ratios of concentrations were smaller than emissions. The reasons were examined in the following subsections.

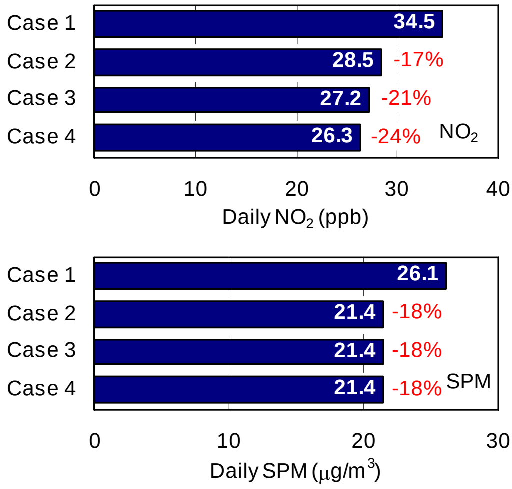

Fig. 6. Predicted NO_2 and SPM concentrations on Dec. 10th, 1999 averaged over the target area.

3.4 Predicted Concentrations of PM Components

Predicted daily concentration of PM components on Dec. 10th, 1999 averaged over the target area in Case 1-4 are shown in Fig. 7. EC, OC and other PM2.5, which are mainly primary emitted components, were reduced in Case 2-4. However, SO_4^{2-}, NO_3^-, NH_4^+, which are mainly secondary components, were not reduced so much. On the other hand, secondary components varied greatly in Case 5 and 6 in which the boundary concentration of the Japan G1 domain was changed. Therefore, secondary components may be much influenced by the transboundary transport. In future, fraction of secondary components is expected to increase, and strategies over wide area including several countries would be necessary to reduce them.

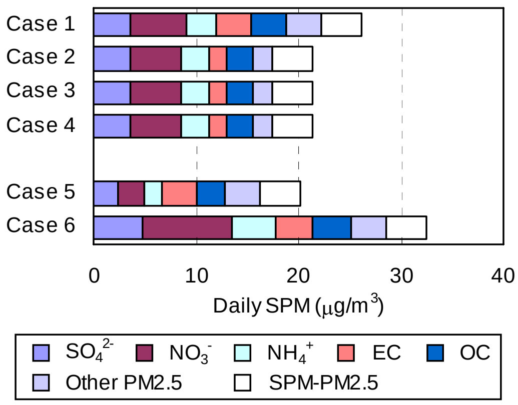

Fig. 7. Predicted concentrations of PM components on Dec. 10th, 1999 averaged over the target area.

3.5 Relation between NOx Emissions and Pollutant Concentrations

Predicted NOx, NO_2 and O_3 concentration in Case 1-6 were plotted against total NOx emissions in the target area in Fig. 8. NOx concentration was headed toward zero as NOx emission decreases. Similar trend was found in NO_2 concentration, but reduction was not as much as NOx. O_3 increased as NOx emission decreases. Most of NOx is emitted as NO, and titrated by O_3 and converted to NO_2 in the atmosphere. Therefore, NO_2 and O_3 concentrations are inversely correlated against NOx emission. In addition, NO concentration in the metropolitan area is so high that a part of NO is not oxidized by O_3 and remains in the atmosphere. NO_2 in the metropolitan area is what is called “O_3 sensitive”. That is why reduction of NO_2 concentration was smaller than NOx. Moreover, NO_2 and O_3 concentration in Case 5 and 6 varied even though the same emission data as Case 1 was used. O_3 may be greatly influenced by the transboundary and hemispheric transport (Akimoto, 2003), and that may affect on the NO - O_3 titration. Strategies on the hemispheric transport of O_3 are important from the viewpoint of NO_2 in the metropolitan area.

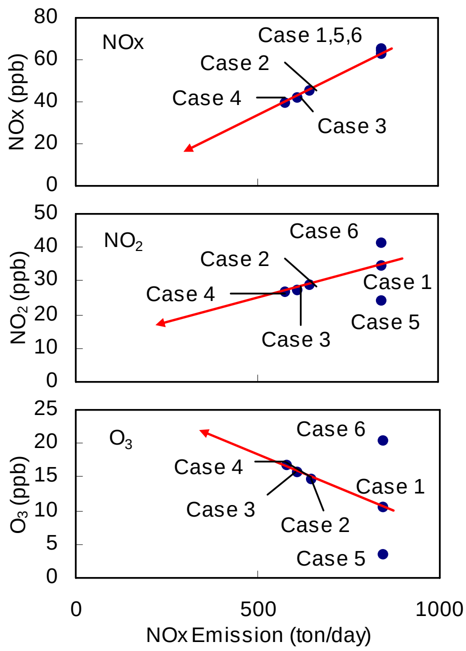

Fig. 8. Predicted NOx, NO_2 and O_3 concentration plotted against total NOx emission in the target area.

4. SUMMARY

By using the JCAP II air quality simulation system, current and future vehicle emissions were estimated by considering the replacement with newer vehicles and regulations, and pollutant concentrations were simulated. As a result, following future directions toward improving air quality in Tokyo metropolitan area were implied.

- Additional regulations on new vehicles may not be effective. High-emitters running in the real-world should be eliminated.
- Reduction of NOx emissions may cause increase of O_3. Overall strategies including NMVOC are important to reduce multiple pollutant concentrations.
- Most of SPM emission would be consisted of road dust and sources except for vehicles.
- Fraction of secondary components in SPM may become larger. The transboundary transport

influences on secondary components of particles and O_3, and even NO_2 in the metropolitan area. Strategies on the transboundary transport are necessary.

It was found that the JCAP II air quality simulation system is a powerful tool for seeking strategies for improving air quality as shown in this paper.

5. ACKNOWLEDGEMENT

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